Exoskeleton for Human Performance Augmentation: The Platform for the Future Combat System (FCS) Soldier

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Two exoskeleton prototypes demonstrate different technological approaches

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EXOSKELETONS

SRC SARCOS RESEARCH CORPORATION

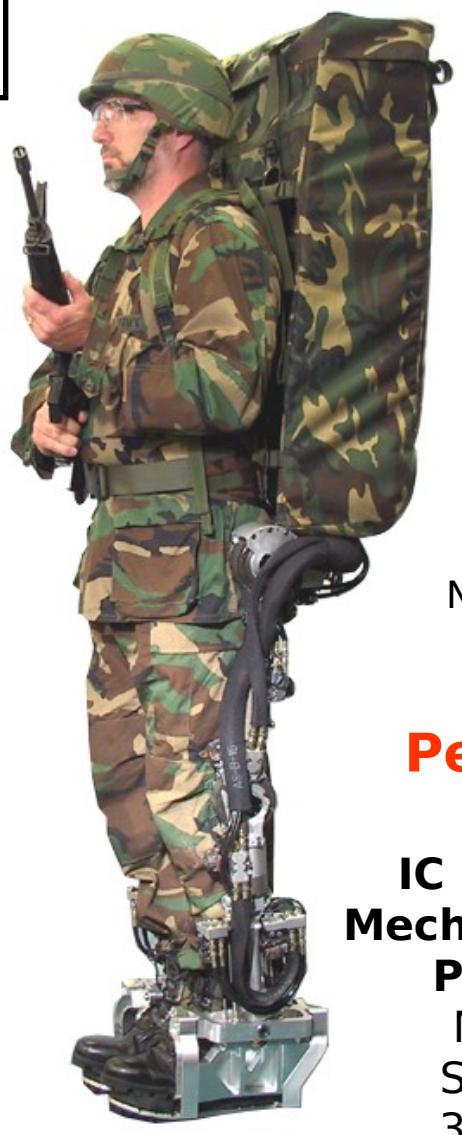
Cal

Hybrid IC Engine and Pump

Custom Servo-Valves
Eliminates power waste during free swing

Tendons
compact packaging

GOOTW Control
Maximizes robustness



Common Features

Ethernet arch real-time processor rugged

Nervous System
Networked local processors

Performance Power

IC Engine Driven Mechanical/Electrical Power Source
Micro-climate
Sensor/comms
3 KW available
Load carriage 200+ lbs

COTS IC Engine/pump

Model Based Control
No sensors touching the wearer

COTS Servo-Valves

COTS Linear Actuators

Think of this as an integrated soldier platform/power supply/transport system—Like a Jeep!

Information Processor

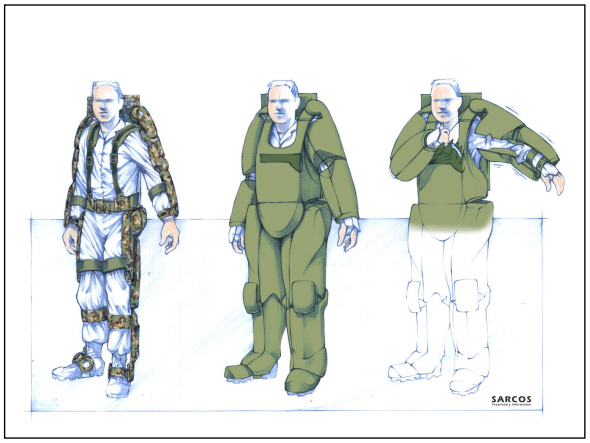
- **Sample collection and analysis**
- **rapid processing and net-centric capabilities**

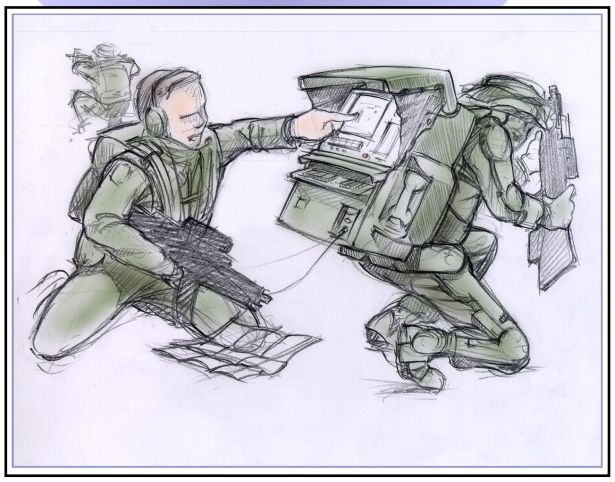
Electrical Power

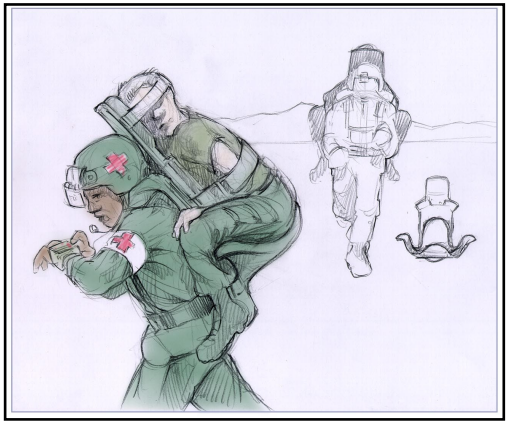
- Micro climate
- Sensor Suites
- Communications
- External power requirements

Mechanical Power

- **Load Carriage**
- **Containment equip**
- **Decontamination equip and supplies**
- **Casualty extraction**



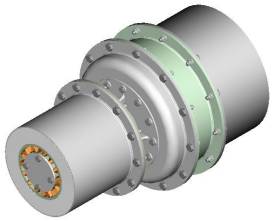




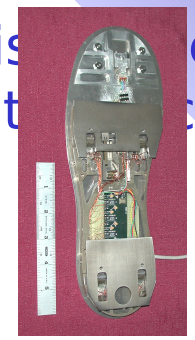
DARPA Exoskeleton Program will enable the soldier with a high capacity, flexible, load-bearing or power platform

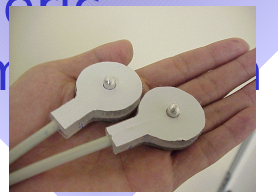
- General technology push in technologies that will enable human “exoskeleton” systems
- Two principal developers, Sarcos Research (lower and upper body) and UC Berkeley (lower body only)
- Ancillary projects in supporting technologies (primarily power and sensors, computational and human interface technology) (3 KWs)

Systems

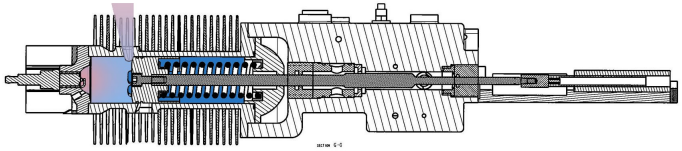


Engines



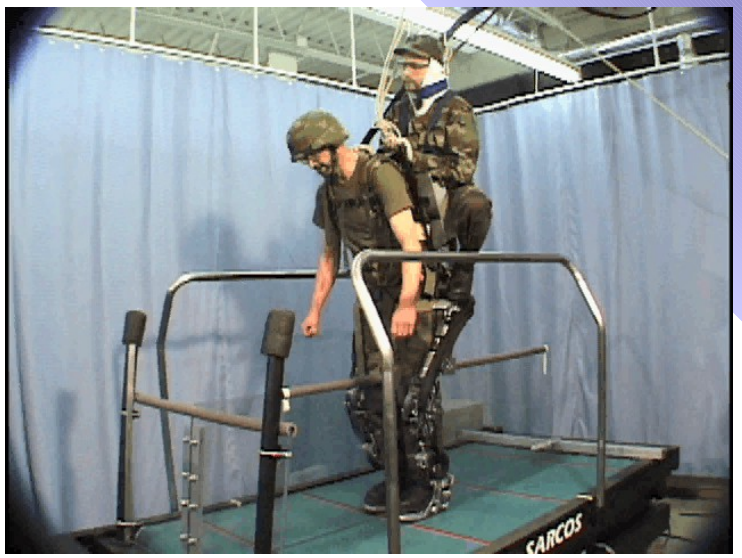


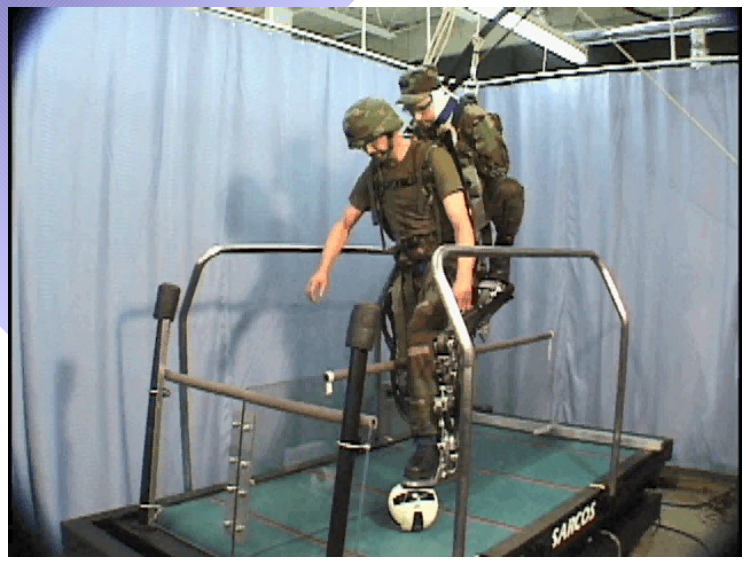
Sensors and Computing



Human Engineering interface and systems integration

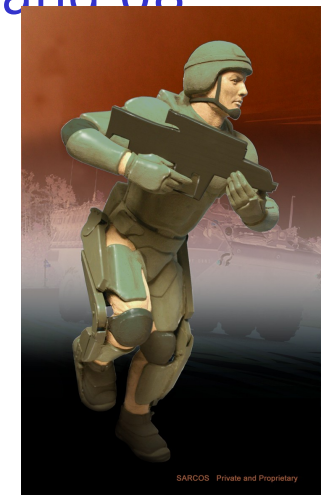
DARPA Exoskeletons
Mechanical and Electrical Power Platform





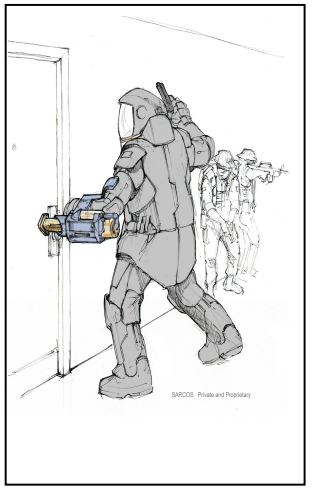
Application Under Development

- Focused development effort aimed at a fast-moving, heavily armored exoskeleton system
- Emphasis is on operation in urban environment
  - Rapid deployment of heavy weapons (XM307)
  - Increase in mass of body armor carried on upper and lower body
  - Rescue of wounded personnel in contested areas
- Focused effort by a single performer leveraging all of the advances made in the Exoskeleton Program
- Program product is 12-14 PCV prototypes delivered in 07 and 08



Light armor for maximum

Medium when greater threats are expected



Heavy breaching variant maximizes

Exoskeleton subsystems will reach TRL 5 by the end of FY05 in present DARPA program

Subsystems	TRL in 8/2004
Lower extremity mechanism	5
Supervisory computer architecture	5
Sensor suite	5
Control Algorithms	4-5
Power train and actuators	4
Power source	3-4
Man-machine interface	3
Upper extremity mechanism	3

Program risk is predominantly in the power source and man-machine interface subsystems because they have never been done before.

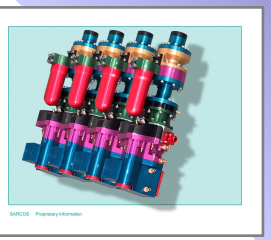
Exoskeleton subsystems will reach TRL 4-5 by the end of FY05 in present DARPA program

Subsystems	TRL in 8/2004
• Lower extremity mechanism	5
• Supervisory computer architecture	5
• Sensor suite	5
• Control Algorithms	4-5
• Power train and actuators	4
• Power source	3-4
• Man-machine interface	3
• Upper extremity mechanism	3

- *TRL 8 – Actual system completed and qualified through test and demonstration*
- *TRL 7 – System prototype demonstration in an operational environment*
- *TRL 6 – Testing of prototypes in simulated operational environment*
- *TRL 5 – Component or subsystem validation in a relevant environment – high level of integration*
- *TRL 4 – Component or subsystem validation in laboratory environment – 'ad hoc' lab setup*
- *TRL 3 – Components bench tested but not yet integrated*
- *TRL 2 – Paper studies*

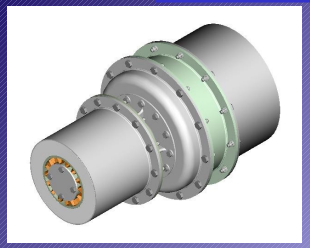
Engines remain a critical component for the Exoskeleton

SARCOS Power Pack



- Modular design permits easy power expansion
- Low idle costs (fires 1 out of 6 revs at idle)
- Integrated engine/hydraulic pump capable of low pressure/high flow and high pressure/low flow

LTS5 Turbo shaft/generator

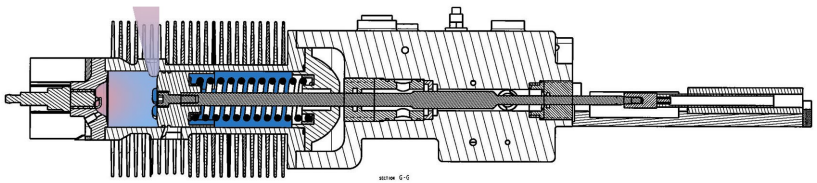


Power = 3.73 kw (5.0 hp)
Weight = 8.0 lbs.
Length = 11.0 in.
Diameter = 6.6 in.

65% less fuel consumption than SOA small turbines

+ 100 hour bearing life demonstrated @ 191,000 rpm

Linear Engine Power Cylinder

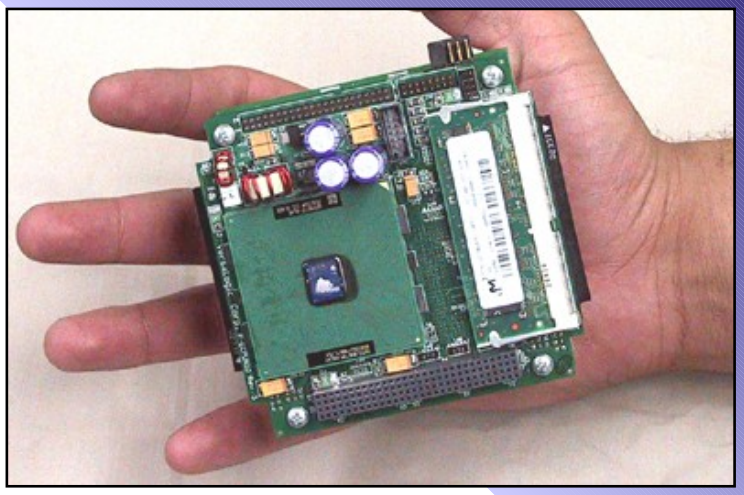


- Integrated IC linear engine and hydraulic pump
- Efficient power on demand
- Instant start/stop with low fuel consumption
- No idling losses

	Rated Power (W)	Eff (%)	Weight (kg)	Specific Power (W/kg)	Fuel Type
Homaltrow Honda 4 stroke	1300	~10	15.9	~80	gas
Locust LTS5	3730	18	3.62	1027	Heavy fuel
Sarcos DDPi	300W per unit	20	1 kg per unit	300 W /kg	Propane (JP-8)
Tiax	900 (1000)	17 (24)	13 (5)	70 (200)	Propane (JP-8)

Performance of the "nervous system" has proven to be adequate for exoskeleton control

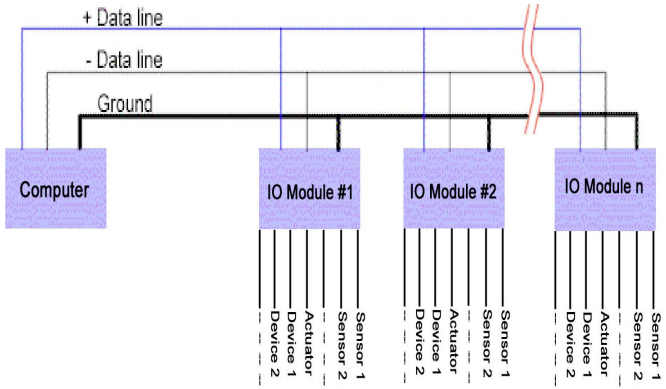
Common High Level Processor



PC 104 format 800 MHz PC Real Time Operating System (RTOS)

- Expandable
- Compact and ruggedized

Ethernet Bus Architecture



200 Mbit/sec network enables real-time control over a serial line. This eliminates wiring bundles and complexity.

- Common expandable bus will accept network ready sensors with USB type interfaces
- Enables hierarchical processing

The extreme forces at the exoskeleton-ground interface drives multiple sensor efforts

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EXOSKELETONS

6-axis Force-Moment Load cell

General specs. load cell ver. 1:

Max. Allowable load:

Fx ~ 1300 lbs; Fy,z ~ 800 lbs;

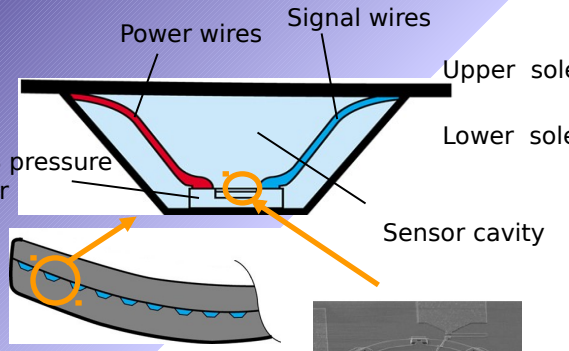
Mx~ 4500 in.-lbs,

My ~ 3450 in.-lbs;

Mz ~ 1000 in.-lbs

Integrated signal conditioning electronics and digital data communication bus interface (Ethernet 10 Mbits/sec)

In-sole Pressure Profiler

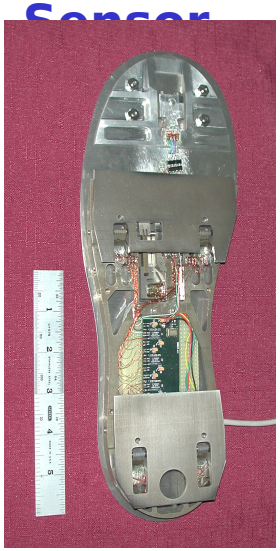


Technical Specs:

Spatial resolution: <= 1 cm2
Pressure resolution: 1%
Pressure repeatability: 5%
Sensing frequency: >= 10 Hz
Mean cycles to failure: >= 0.5x106

Sandia National Laboratories

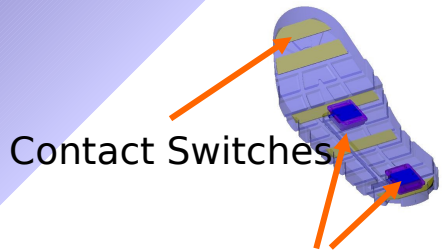
7-Axis Reaction Force/Torque Sensor

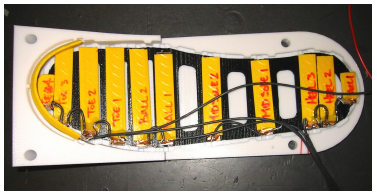


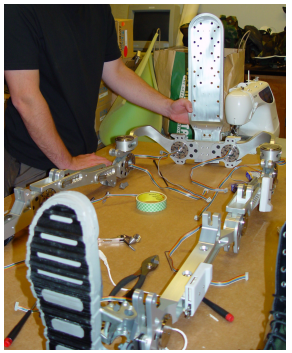
- Total Height 1.03 Inches For Biomechanical Version (.73 Sensor Height Plus .3 inch Bottom Tread Thickness)
- Total Sensor Mass 1.85 lb
- .25 lbf Resolution (per load cell)
- Static and Dynamic Sensing
- 12 inch Minimum Radius of Curvature
- Attaches to Military-Style Boot

ornl

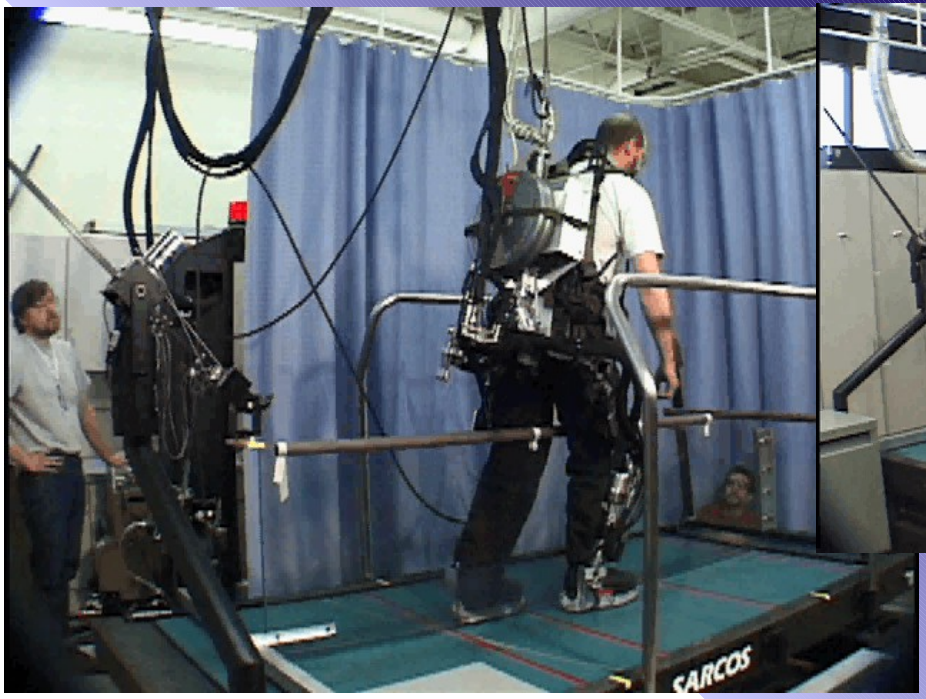
Footpad Switch Array

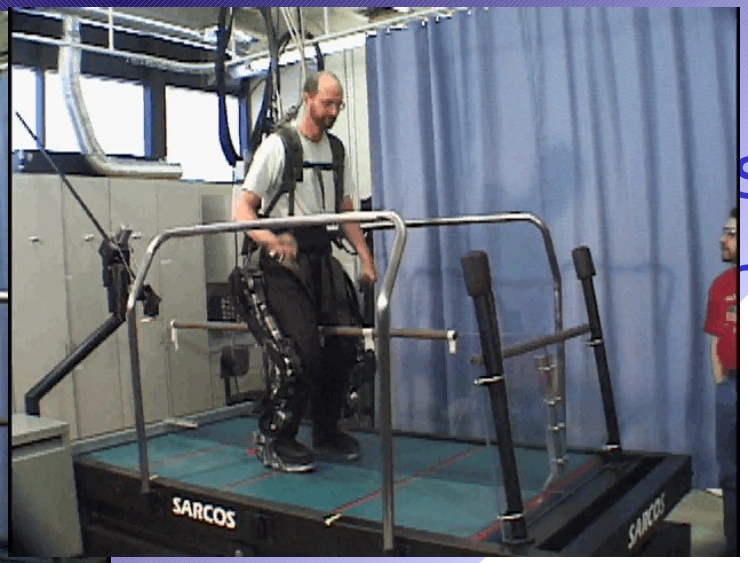






DARPA Exoskeletons – Laboratory Evaluations





- Flat Surface Walking
- UC Berkeley Exoskeleton

- Further questions should be directed to:

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